Human Experimental Toxicology (1999) 18, 297–301

http://www.stockton-press.co.uk/het

Assessment of the exposure of children to environmental tobacco smoke (ETS) by different methods

Gerhard Scherer*,[1], Irmtrud Meger-Kossien[1], Kirsten Riedel[1], Thomas Renner[1] and Michael Meger[1]

[1]*Analytisch-biologisches Forschungslabor München (ABF), Goethestrasse 20, D-80336 München, Germany*

1 In order to elucidate the role of exposure to environmental tobacco smoke (ETS) in various acute and chronic illnesses in children, it is important to assess the degree of exposure by suitable methods. For this purpose, we determined the exposure to ETS in 39 children (4–15 years) and 43 adults (16+ years) by questionnaires, personal diffusion samplers for nicotine, and cotinine measurements in saliva and urine. In addition, the influence of the smoking status and the location of the home (urban or suburban) on the benzene exposure of the children was investigated.

2 On average, the 24 children living in homes with at least one smoker were exposed to ETS for 3.1 h/d. This is significantly longer ($P<0.001$) than the daily exposure time of the 15 children from nonsmoking homes (0.3 h/d). The nicotine concentrations on the personal samplers worn over 7 days were 0.615 and 0.046 $\mu g/m^3$ for children from smoking and nonsmoking homes, respectively ($P<0.001$). Average salivary cotinine levels were 1.95 ng/ml in children from smoking homes and 0.11 ng/ml in children from nonsmoking homes ($P<0.01$). The corresponding urinary cotinine levels were 29.4 and 4.5 ng/mg creatinine ($P<0.001$). There was no difference in the extent of ETS exposure between children and adults from smoking households. Adults from nonsmoking homes tended to have higher ETS exposure than children from nonsmoking homes.

3 Exposure to benzene, which was determined by means of personal samplers, measurements of benzene in exhaled air and of the urinary benzene metabolite *trans, trans*-muconic acid, was not significantly related to the smoking status of the home but primarily dependent on the location of the home.

Keywords: environmental tobacco smoke; children; cotinine; benzene; personal sampler

Introduction

Exposure of children to environmental tobacco smoke (ETS) has been implicated with the development of respiratory symptoms and illnesses, impaired pulmonary function or lung growth, and middle ear effusion.[1] A correct and practicable assessment of the exposure dose is required in order to elucidate the role of ETS exposure in the development of these diseases. The smoking status of the spouse has been most commonly used as an indicator for ETS exposure in epidemiological studies when studying outcomes with a long latency period.[2] In studies with children, the smoking habit of the parents, particularly maternal smoking,[3–5] would be the equivalent. Questionnaires in which the duration and extent of ETS exposure are reported can supply information on the more recent exposure.[5,6] For preschool-children, their parents most often supply this information. Stationary measurements of nicotine in different environments represent indirect assessment methods for ETS exposure.[2] The most important environment for children is certainly their home. A more direct exposure assessment can be performed by using personal samplers for nicotine.[2] Passive diffusion samplers for nicotine[7] work without a pump, are lightweight and thus most suitable as personal monitors for children. Cotinine in body fluids is a suitable biomarker for ETS exposure.[8,9] Body fluids which are non-invasively available, such as saliva and urine, are considered to be most appropriate for studies with children.

The purpose of our study was to determine the extent of children's exposure to ETS by the assessment methods mentioned above and to compare it to the ETS exposure of adults. In addition, the benzene exposure was measured by personal monitors and biomonitoring. The relation between the extent of benzene exposure and the smoking status as well as the location of the home was investigated.

*Correspondence: G Scherer
Received 6 August 1998; revised 25 September 1998; accepted 26 October 1998
Presented at the International Academic Symposium on '*Passive Smoking & Children: Clinical and Experimental Forums*', August 24–25, 1998, Essen University School of Medicine, D-45147 Essen, Germany

?âÞ'J< (ÁÞ±" zÃAÞ~"■ċ

Methods

Study design and subjects

he study has been described previously.[10] The original aim was to determine the contribution of ETS and other sources to the benzene exposure in adults and children. In this paper, the ETS exposure situation of children was evaluated. Briefly, 20 households with at least one smoker ('smoking home') and ten households without smokers ('nonsmoking home') located in the city and suburbs of Munich were investigated. Each household had at least three members aged ⩾4 years who participated in the study. Altogether, 82 nonsmokers, of whom 39 were 4–15 years-old, participated. Passive diffusion samplers for nicotine and benzene were placed in the living room for a 1-week sampling period. All subjects wore the same type of passive sampler for 7 days during the daytime and placed the samplers on a bedside table at night. During the first and second visit (7 days later) to the household, saliva, spot urine, and exhalate samples were collected from each subject. Since similar results were obtained from both visits, only the results of the second visit are reported here.

Questionnaire

Each subject completed a questionnaire on their exposure to ETS. Younger children were assisted by their parents. Time, duration, and intensity of each exposure was recorded on separate sheets, structured on an hourly basis for each of the 7 study days. The intensity was classified by the subject as low (score=1), medium (=2) and high (=3). An intensity score of the exposure was calculated by multiplying the duration (h/d) with the corresponding intensity.

Air measurements and personal monitoring

Nicotine was collected on passive diffusion samplers, which were worn by the subjects as personal monitors or deposited in the living room over 7 days. Nicotine analysis was performed as described by Ogden and Maiolo.[7] The detection limit was 0.01 $\mu g/m^3$. Benzene was collected on passive diffusion samplers (ORSA 25, Dräger AG, Lübeck, Germany) worn by the nonsmokers as personal monitors over 7 days and afterwards stored at −25°C in sealed glass vials covered with aluminium foil. Benzene analysis was performed according to the NIOSH method[11] by GC/MS (Hewlett Packard, Model 5890/Series II coupled with a mass selective detector Model MSD 5972) using 'cold on-column' injection (Gerstel Model GC 6105-99, Mühlheim, Germany). The detection limit was 0.3 $\mu g/m^3$.

Biomonitoring

Saliva samples were collected using cellulose dental swabs sealed in hygienic vials (Salivetten, Sarstedt, Nümbrecht, Germany). After chewing for 2 min, the swab was returned to the vial which was sealed and stored at −20°C prior to analysis. Cotinine in saliva and urine was determined by radioimmunoassay (RIA) according to the method of Langone *et al.*,[12] modified by Haley *et al.*[13] The detection limits were 0.1 ng/ml for cotinine in saliva and 0.5 $\mu g/g$ creatinine for urinary cotinine. For benzene determination, exhaled air (1–2 l in 2 min) was sampled using a modified device originally described by Raymer *et al.*[14] and modified by us.[15] The limit of detection was 0.4 $\mu g/m^3$. Urinary *trans, trans*-muconic acid was determined by GC/MS (Hewlett Packard GC Model 5890/Series II with a mass selective detector MSD 5972, Waldbronn, Germany) as described elsewhere.[16] The limit of detection was 0.01 mg/g creatinine. Urinary creatinine was determined by the Jaffé method using a commercial test kit (Merck AG, Darmstadt, Germany).

Table 1 ETS exposure of children and nonsmoking adults classified according to smoking status of their home

	Means (Medians) (Ranges)			
	Nonsmoking homes		*Smoking homes*	
	Children (n=15)	*Adults (n=24)*	*Children (n=24)*	*Adults (n=19)*
Age (years)	11.1 [11] (4–15)	38.4 [43] (16–53)	8.2 [8.5] (4–14)[a]	35.9 [36] (16–62)
Nicotine in the living room ($\mu g/m^3$)	0.025 [0.03] (nd[b]–0.06)	0.02 [0.01] (nd–0.06)	4.17 [1.04] (0.20–34.6)***	4.11 [3.70] (0.20–23.2)
ETS exposure duration (h/d)	0.33 [0.30] (0.0–1.0)	0.77 [0.45] (0.0–3.5)	3.14 [2.10] (0.0–11.4)***	3.15 [2.90] (0.0–13.4)
ETS exposure intensity (score)	0.43 [0.4] (0.0–1.6)	1.25 [0.6] (0.0–5.9)	3.50 [2.80] (0.0–16.9)***	4.67 [3.90] (0.0–23.5)
Nicotine on the personal sampler ($\mu g/m^3$)	0.049 [0.025] (nd–0.24)	0.19 [0.100] (nd–1.10)*	0.615 [0.285] (0.05–4.10)***	0.93 [0.400] (0.08–4.57)
Cotinine in saliva (ng/ml)	0.11 [nd] (nd–0.45)	0.40 [0.15] (nd–2.4)	1.95 [1.05] (nd–8.3)***	1.52 [0.90] (nd–5.0)
Cotinine in urine ($\mu g/g$ creatinine)	4.5 [2.4] (0.26–27.8)	6.2 [4.8] (nd–26.4)	29.4 [9.1] (2.2–159)***	19.4 [13.1] (3.5–68.2)

[a]Mann-Whitney rank sum test for differences compared to children from nonsmoking homes: *$P<0.05$, ***$P<0.001$; significance levels for differences between adults from smoking homes and children or adults from nonsmoking homes are not shown. [b]nd: not detectable, for limits of detection (LOD) see Methods section

Statistical analysis

Since most of the variables deviated from a normal distribution, the Mann-Whitney rank sum test was used for comparison of groups.

Results

The means, medians and ranges for the ETS exposure markers of children and adults determined in this study are shown in Table 1. Children from smoking homes were, on average, about 3 years younger than children from nonsmoking homes. Both, the self-reported extent of ETS exposure (i.e. duration and intensity of ETS exposure) and the objectively measured ETS exposure markers, were significantly higher ($P<0.001$) for children from smoking homes compared to children from nonsmoking homes. The ratio of the medians for children between the two types of homes ranged from 3.8 for cotinine in urine to 11.4 for nicotine on the personal samplers (Table 2). For adults, the ratio ranged from 2.7 for urinary cotinine to 6.5 for the score of ETS exposure intensity. The ratio between the median nicotine concentrations in the living rooms of smoking and nonsmoking homes was 34.7 for children and 70.0 for adults. The ETS exposure levels of adults from smoking homes were not significantly different from that of children from smoking homes. The individual ETS exposure levels of adults from nonsmoking homes tended to be higher than those of children from nonsmoking homes. For nicotine on the personal samplers, the difference was statistically significant ($P<0.05$).

There was a significant correlation between the measured ETS exposure markers and the self-reported extent of ETS exposure (Table 3). For children, the correlation was somewhat stronger between the ETS exposure markers and the reported duration of ETS exposure than between the markers and the self-estimate for the ETS exposure intensity. For adults, the observed correlations were weaker than for children. For both children and adults, the strongest correlation was found between urinary cotinine levels and the reported ETS exposure duration. Exposure of children to benzene tended to be higher when living in a smoking home and when the home was located in the urban area of Munich (Table 4). However, there was a large inter-individual variation in benzene exposure levels. The differences in benzene exposure levels between children from smoking and nonsmoking homes were

Table 2 Ratios (smoking homes/nonsmoking homes) of the medians of ETS exposure markers for children and adults

	Children	*Adults*
Nicotine in the living room ($\mu g/m^3$)	34.7	70.0
ETS exposure duration (h/d)	7.0	6.4
ETS exposure intensity (score)	7.0	6.5
Nicotine on the personal sampler ($\mu g/m^3$)	11.4	4.0
Cotinine in saliva (ng/ml)	–	6.0
Cotinine in urine (ng/g creatinine)	3.8	2.7

Table 3 Pearson coefficient of correlation between self-reported and measured ETS exposure markers for children and adults from smoking and nonsmoking homes

Measured ETS exposure markers	*Self-reported extent of ETS exposure*	
	Duration (h/d)	*Intensity-score*
Children (n=39)		
Nicotine on personal sampler ($\mu g/m^3$)	0.56***[a]	0.48**
Cotinine in saliva (ng/ml)	0.58***	0.48**
Cotinine in urine ($\mu g/g$ creatinine)	0.80***	0.76***
Adults (n=43)		
Nicotine on personal sampler ($\mu g/m^3$)	0.30*	0.36*
Cotinine in saliva (ng/ml)	0.29	0.30*
Cotinine in urine ($\mu g/g$ creatinine)	0.58***	0.50***

[a]Levels of statistical significance: *$P<0.05$, **$P<0.01$, ***$P<0.001$

Table 4 Benzene exposure of children according to smoking status and location of their home: Means [Medians] (Ranges)

	Benzene on personal samplers ($\mu g/m^3$)	*Benzene in exhalate ($\mu g/m^3$)*	*t,t-Muconic acid in urine ($\mu g/g$ creat.)*
Smoking status of the home			
Nonsmoking (n=15)	19.7 [6.9] (3.5–129.4)	2.1 [1.3] (nd[a]–10.5)	112 [62] (40–274)
Smoking (n=24)	11.5 [12.6] (1.6–32.6)	3.6 [1.9] (nd–21.2)	130 [85] (40–402)
Location of the home			
Suburban (n=21)	8.6 [4.1] (1.6–32.6)	2.4 [0.8] (nd–21.2)	115 [68] (40–402)
Urban (n=18)	19.6 [12.3][b] (4.5–129.4)	3.8 [2.7]* (0.6–14.9)	133 [85] (50–330)

[a]nd: not detectable, for limits of detection (LOD) see Methods section. [b]Mann-Whitney rank sum test for differences between children living in urban and suburban homes: *$P<0.05$; differences in benzene exposure levels between children living in nonsmoking and smoking homes were not significant

living in urban and suburban homes: *$P<0.05$; differences in benzene exposure levels between children living in nonsmoking and smoking homes were not significant

not statistically different. Children living in urban homes had, on average, significantly higher ($P<0.05$) benzene levels on their personal sampler and showed significantly higher ($P<0.05$) benzene concentrations in their exhalate than children from suburban homes. The strata 'urban/suburban' and 'smoking/nonsmoking' was equally distributed in the study population: 47% (7 of 15) of children from nonsmoking households lived in an urban home. The corresponding figure for smoking households was 46% (11 of 24). 62% (13 of 21) of children living in the suburbs, had a smoking home. The corresponding figure for children from urban homes is 61% (11 of 18).

Discussion

Our results clearly show that the home is the most important source for children's exposure to ETS. This confirms findings of earlier studies.[3,4,17–25] A survey in West Germany in 1987 has shown that the prevalence of 6–13 years old children with at least one smoking household member is 67.5%.[20] Thus, ETS exposure at home is a common exposure for children. The exposure levels observed in our study are similar to those found in other investigations.[10] Based on the median ETS exposure levels determined by different methods, we found that children from smoking homes are 3.8–11.4 times more exposed to ETS than children from nonsmoking homes (Table 2). For adults, these ratios were slightly lower (2.7–6.4). ETS exposure levels for children and adults from smoking homes were not significantly different. Comparison of cotinine-deduced ETS exposure levels presumes similar half-lifes of cotinine in children and adults. We assume that the half-life of cotinine for children aged 4–15 years is comparable to that of adults (16+ years) in our study.[27] On the other hand, adults from nonsmoking homes tended to show higher ETS exposure than children from nonsmoking homes. For the nicotine concentration on the personal sampler this difference was significant. This reflects the fact that for adults from nonsmoking homes, ETS exposure at the workplace and during leisure time outside the home plays an additional role.

In other studies, the ETS exposure ratio between children from smoking and nonsmoking homes was reported to be about three.[21–24,28] In some investigations this ratio was found to exceed 10.[4,5,17,20,25]

We found a significant correlation between the measured ETS exposure markers (nicotine on personal samplers, cotinine in saliva and urine) and the self-reported extent of ETS exposure (duration of exposure per day, intensity of exposure) (Table 3). Correlations were found to be stronger for children than for adults. A probable explanation for this finding is that children's exposure to ETS occurred almost exclusively at home, whereas adults were exposed at various places, which appears to be more difficult to be estimated by the subject. It is interesting to note that the self-reported intensity of ETS exposure does not improve the correlation for adults and even weakens the correlation for children. This finding is in contrast to studies, which showed that subject's perception of the smokiness at home was an independent indication of a high urinary cotinine level.[5,23] According to our results, the reported duration of ETS exposure in hours per day is sufficient as a predictor for the objectively measurable ETS exposure.

Our results suggest that the methods applied by us are almost equally good for the assessment of children's exposure to ETS. With respect to questionnaire data, the smoking status of the home and the reported hours of ETS exposure per day are the strongest predictors. Assessing the subject's perception of the intensity of the ETS exposure does not improve the agreement with the measurable exposure markers. Practical considerations should prevail when selecting suitable ETS exposure markers in studies with children. Collection of spot urine and saliva samples for cotinine measurements is non-invasive and easy to perform with children. According to our experience, wearing a personal sampler for nicotine over several days may be problematic with children. As already recommended by other authors,[2] applying a combination of different methods could be often the best approach.

Our results on the benzene exposure of children show that the smoking status of the home is only a weak predictor (Table 4). Living in an urban home appears to be more important for the benzene exposure. This finding is in line with an investigation showing that benzene concentrations in children's bedrooms were not significantly different between smoking and nonsmoking homes.[29] The authors stated that traffic exhausts and redecorations were the main contributors to indoor benzene levels. In another study,[30] children living in urban areas were found to have higher benzene blood concentrations than children living in rural areas.

Taken together, we conclude that for children aged 4–15 years, the home is the most important source of ETS exposure. The extent of ETS exposure can best be assessed by a combination of self-reported duration of ETS exposure per day and cotinine measurements in saliva or urine. When evaluating exposure or effects of ubiquitously occurring toxicants, such as benzene, other sources have to be considered as well.

Acknowledgements

This study was supported by a grant from the Forschungsgesellschaft Rauchen und Gesundheit, Hamburg, Germany.

References

1 Hood RD, *et al.* Environmental Tobacco Smoke Exposure and Respiratory Health in Children: An Updated Critical Review and Analysis of the Epidemiological Literature. *Indoor Environment* 1992; **1**: 19–35.

2 Jaakkola MS, Jaakkola JJK. Assessment of exposure to environmental tobacco smoke. *European Respiratory Journal* 1997; **10**: 2384–2397.

3 Coultas DB, *et al.* Salivary cotinine levels and involuntary tobacco smoke exposure in children and adults in New Mexico. *American Reviews of Respiratory Diseases* 1987; **136**: 305–309.

4 Cook DG, *et al.* Passive exposure to tobacco smoke in children aged 5–7 years: individual, family, and community factors. *British Medical Journal* 1994; **308**: 384–389.

5 Forastiere F, *et al.* Questionnaire data as predictors of urinary cotinine levels among nonsmoking adolescents. *Archives of Environmental Health* 1993; **48**: 230–234.

6 Coultas DB, Peake GT, Samet JM. Questionnaire assessment of lifetime and recent exposure to environmental tobacco smoke. *American Journal of Epidemiology* 1989; **130**: 338–347.

7 Ogden MW, Maiolo KC. Comparative evaluation of diffusive and active sampling systems for determining airborne nicotine and 3-ethenylpyridine. *Environmental Science & Technology* 1991; **26**: 1226–1234.

8 Benowitz NL. Cotinine as a biomarker of environmental tobacco smoke exposure. *Epidemiology Reviews* 1996; **18**: 188–204.

9 Scherer G, Richter E. Biomonitoring exposure to environmental tobacco smoke (ETS): A critical reappraisal. *Human and Experimental Toxicology* 1997; **16**: 449–459.

10 Scherer G, *et al.* Contribution of tobacco smoke to environmental benzene exposure in Germany. *Environment International* 1995; **21**: 779–789.

11 NIOSH. Manual of Analytical Methods, Method 1500/1501 (1984) US Department of Health and Humans Services, vol 1, pp 84–100.

12 Langone J, Gjika HB, Van Vunakis H. Nicotine and its metabolites: Radioimmunoassay for nicotine and cotinine. *Biochemistry* 1973; **12**: 5025–5030.

13 Haley NJ, Axelrad CM, Tilton KA. Validation of self-reported smoking behaviour: Biochemical analyses of cotinine and thiocyanate. *American Journal of Public Health* 1983; **73**: 1204–1207.

14 Raymer JH, *et al.* A device for sampling of human alveolar breath for the measurement of expired volatile organic compounds. *Journal of Analytical Toxicology* 1990; **14**: 337–344.

15 Riedel K, *et al.* Determination of benzene and alkylated benzenes in ambient and exhaled air by microwave desorption coupled with gas chromatography-mass spectrometry. *Journal of Chromatography* 1996; **719**: 383–389.

16 Ruppert T, *et al.* Determination of urinary *trans, trans*-muconic acid by gas chromatography-mass spectrometry. *Journal of Chromatography* 1995; **666**: 71–76.

17 Jarvis MJ, Strachan DP, Feyerabend C. Determinants of passive smoking in children in Edinburgh, Scotland. *American Journal of Public Health* 1992; **82**: 1225–1229.

18 Bono R, *et al.* Involuntary exposure to tobacco smoke in adolescents: Urinary cotinine and environmental factors. *Archives of Environmental Health* 1996; **51**: 127–131.

19 Chan C-C, Chen S-C, Wang J-D. Relationship between indoor nicotine concentrations, time-activity data, and urine cotinine-creatinine ratios in evaluating children's exposure to environmental tobacco smoke. *Archives of Environmental Health* 1995; **50**: 230–234.

20 Strachan DP, Jarvis MJ, Feyerabend C. Passive smoking, salivary cotinine concentrations, and middle ear effusion in 7 year old children. *British Medical Journal* 1989; **298**: 1549–1552.

21 Jarvis MJ, *et al.* Factors determining exposure to passive smoking in young adults living at home: Quantitative analysis using saliva cotinine concentrations. *International Journal of Epidemiology* 1991; **20**: 126–131.

22 Weaver VM, *et al.* Environmental tobacco smoke exposure in inner-city children. *Cancer Epidemiology, Biomarkers & Prevention* 1996; **5**: 135–137.

23 Dell'Orco V, *et al.* Houshold and community determinants of exposure to involuntary smoking: A study of urinary cotinine in children and adolescents. *American Journal of Epidemiology* 1995; **142**: 419–427.

24 Rylander E, *et al.* Exposure to environmental tobacco smoke and urinary excretion of cotinine and nicotine in children. *Acta Peadiatrica Scandinavica* 1989; **78**: 449–450.

25 Henderson FW, *et al.* Home air nicotine levels and urinary cotinine excretion in preschool children. *American Reviews of Respiratory Diseases* 1989; **140**: 197–201.

26 Brenner H, Mielck A. Children's exposure to parental smoking in West Germany. *International Journal of Epidemiology* 1993; **22**: 818–823.

27 Collier AM, *et al.* Cotinine elimination and its use as a biomarker in young children involuntarily exposed to environmental tobacco smoke. *Indoor Environment* 1994; **3**: 353–359.

28 Nafstad P, *et al.* Comparison of three methods for estimating environmental tobacco smoke exposure among children aged between 12 and 36 months. *International Journal of Epidemiology* 1995; **24**: 88–94.

29 Porstmann F, *et al.* Benzol und Toluol in Kinderzimmern. *Staub-Reinhaltung der Luft* 1994; **54**: 147–153.

30 Jermann E, *et al.* Belastung von Kindern durch Benzol und andere verkehrsbedingte Immissionen. *Zbl. Hyg.* 1989; **189**: 50–61.